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Award Number: DAMD17-02-1-0295

TITLE: An Evaluation of Stereoscopic Digital Mammography for Earlier Detection of Breast Cancer and Reduced Rate of Recall

PRINCIPAL INVESTIGATOR: David J. Getty, Ph.D.

CONTRACTING ORGANIZATION: BBN Technologies Solutions, LLC  
Cambridge, MA 02138

REPORT DATE: August 2005

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;  
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**1. REPORT DATE (DD-MM-YYYY)**  
01-08-2005**2. REPORT TYPE**  
Annual**3. DATES COVERED (From - To)**  
1 Aug 2004 – 31 Jul 2005**4. TITLE AND SUBTITLE**

An Evaluation of Stereoscopic Digital Mammography for Earlier Detection of Breast Cancer and Reduced Rate of Recall

**5a. CONTRACT NUMBER****5b. GRANT NUMBER**  
DAMD17-02-1-0295**5c. PROGRAM ELEMENT NUMBER****6. AUTHOR(S)**

David J. Getty, Ph.D.

**5d. PROJECT NUMBER****5e. TASK NUMBER****5f. WORK UNIT NUMBER**E-mail: [getty@bbn.com](mailto:getty@bbn.com)**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**BBN Technologies Solutions, LLC  
Cambridge, MA 02138**8. PERFORMING ORGANIZATION REPORT NUMBER****9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012**10. SPONSOR/MONITOR'S ACRONYM(S)****11. SPONSOR/MONITOR'S REPORT NUMBER(S)****12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for Public Release; Distribution Unlimited

**13. SUPPLEMENTARY NOTES**

Original contains color plates: All DTIC reproductions will be in black and white.

**14. ABSTRACT**

The goal of this project is to evaluate, in a screening context, stereoscopic digital mammography versus standard, non-stereo digital mammography for the earlier detection of breast lesions during screening and reductions in the rate of patient recall for further work-up. During the project, more than 100 women at elevated risk for development of breast cancer will receive both standard (non-stereo) and stereo digital mammograms at the Emory Breast Clinic.

In this third year of the project, we completed and installed new improved stereo display workstations at BBN and Emory, each based on a pair of high-resolution, Planar LCD medical monitors. We improved and added functionality to our software application, SDM Viewer, used by the participating mammographers to control many aspects of the displayed stereo mammograms. The study data forms were completed and revised, and data entry screens were developed for importation of case data into an SPSS database.

We began enrolling patients into the study beginning in January of 2005. At the end of Year 3, we had imaged and processed 120 patients. While this sample is too small for statistical analysis, the early results look very promising for stereo mammography.

**15. SUBJECT TERMS**

Stereoscopic digital mammography, breast cancer detection, reduced rate of recall, focal abnormality detection

**16. SECURITY CLASSIFICATION OF:****a. REPORT**  
U**b. ABSTRACT**  
U**c. THIS PAGE**  
U**17. LIMITATION OF ABSTRACT**

UU

**18. NUMBER OF PAGES**

33

**19a. NAME OF RESPONSIBLE PERSON**  
USAMRMC**19b. TELEPHONE NUMBER (include area code)**

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## INTRODUCTION

The objective of this project is to evaluate stereoscopic digital mammography in a screening setting, compared to standard, non-stereo digital mammography, for early detection of breast cancer and for reduced rate of patient recall. We hypothesize that by viewing the internal structure of the breast in depth, a mammographer will be able to detect subtle lesions in the breast earlier and with greater accuracy. When seen directly as a volumetric structure, a benign lesion may be more confidently dismissed without further work-up. We also believe that the stereo mammogram will reduce false positive detections of apparent lesions—chance superimpositions of normal tissue that in the standard non-stereo mammogram resemble a volumetric focal abnormality. In the stereo mammogram, the otherwise superimposed tissue is seen as separated in depth. As a result, we believe that fewer patients will need to be recalled for further work-up of what turn out to be false positives. Over the remaining two years of the project, more than 1000 women who are at elevated risk for development of breast cancer, because of personal or family history, will be enrolled in the project and given both standard (non-stereo) and stereoscopic digital mammography screening examinations. The standard and stereo mammographic images will be interpreted in independent readings by different mammographers. The reading data will be analyzed to determine the comparative rates of true lesion detection, and of appropriate recall for further work-up.

## **BODY OF REPORT**

### **1. Overview of Year 3 Progress**

Early in Year 3, the new stereo display workstation, developed during Year 2, was installed at the Emory University Breast Clinic. The five participating mammographers were trained in the use of the stereo display and its control software. During the fall months, features were added to the SDM Viewer software application and its operation was refined, based on feedback from the Emory mammographers.

The study forms to be filled out for each enrolled patient were also modified and improved during the fall through discussions with Carl D'Orsi and Ellen D'Orsi at Emory. Additional minor adjustments to improve the information captured on each case were made at several points during the project year.

We developed the means to transfer the stereo case images from the acquiring GE Senographe digital mammography unit directly to the stereo display workstation for viewing there. We also developed software to anonymize the DICOM file headers of a given case's images, ZIP the images into a single file, and then transmit the anonymized case to BBN for quality assurance testing and archival storage.

During Year 3, we also developed the project database for storing case data, using the SPSS data analysis system. We wrote SPSS software scripts that present the user with a series of data entry screens to facilitate the data entry process.

We began enrolling and imaging patients in January of 2005. To date, we have processed the records for 120 patients (about 150 patients have been imaged to date). We have begun a public relations campaign in the southeastern U.S. to increase the rate at which patients request enrollment into the study.

### **2. Installation of the new stereo display workstation at Emory**

In late August, 2004, Drs. Getty and Pickett traveled to Emory University to oversee the installation of the stereo display workstation (shown below in Figure 1) in the Emory Breast Clinic. The workstation includes the new dual-LCD-based Planar StereoMirror stereo display developed in the prior year. Planar engineering personnel were present to assemble and align the components of the stereo display.

Drs. Getty and Pickett held training sessions with the Emory mammographers and research staff to educate them in the use of the SDM Viewer software application for interactive viewing and control of stereo mammograms on the workstation. They also reviewed the research protocol to be followed in the study with Dr. Carl D'Orsi, PI for the clinical aspects of the project at Emory, and with Ellen D'Orsi, research administrator for the project at Emory.



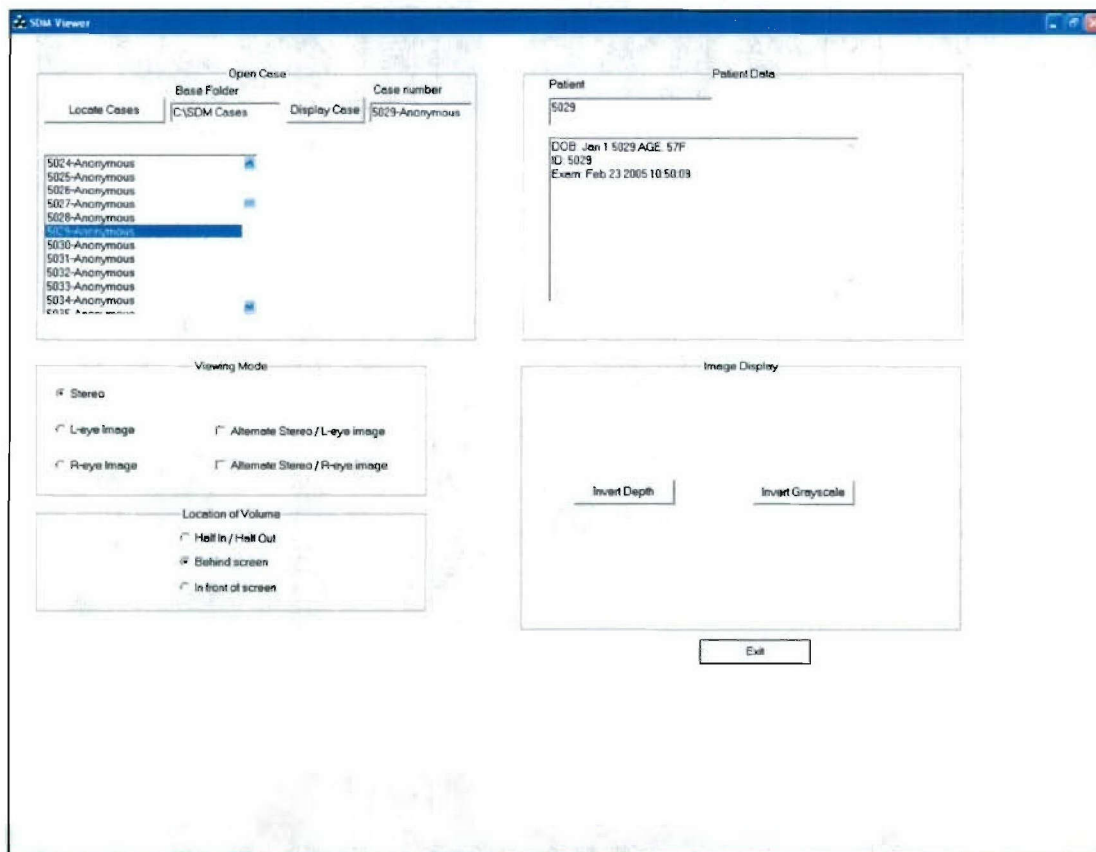
**Figure 1. Stereo display workstation, including the Planar StereoMirror display.**

### **3. SDM Viewer software application**

We described the initial version of the SDM Viewer program in detail in last year's annual report. During this past year, we made four modifications to the application. The first modification was to add a capability for the user to choose a different base directory from which to choose stereo mammography cases for viewing (the default directory is "C:\SDM Cases"). This enhancement permits definition of special subsets of cases for viewing, and is also convenient for testing purposes with special test images. The selection of a different base directory is made using the window shown in the upper left of Figure 2.

The second modification was to add a third possible location for the displayed volume relative to the display screen surface—"half in / half out". In this display mode, the displayed volume is bisected by the screen surface, so that the front half of the volume lies in front of the display screen while the rear half lies behind the screen surface. The effect of this location of the stereo volume is that the absolute magnitude of the experienced parallax in the stereo image is half as large as that experienced with either the full in or full out modes of display. The possible disadvantage of this method of display is that the visual system experiences both crossed parallax (for portions of the image perceived to lie in front of the screen) and uncrossed parallax (for portions of the image perceived to lie behind the screen) within the same image. We initially set the default viewing mode to be this new mode, "half-in / half-out". But, as the mammographers gained experience in viewing stereo mammograms throughout this past year, it appeared that they preferred, for reasons of visual comfort, to view the display volume as lying entirely behind the screen. As a result, we changed this to be the new default. However, a

mammographer may freely set the viewing mode to any of the three options by clicking on the appropriate radio button, shown in the lower left of Figure 2.



**Figure 2. Control window of the SDM Viewer software application.**

The third modification to the SDM Viewer was necessitated by the fact that some patients enrolled in the study had previously had a breast removed in a mastectomy. For these patients, the case images consisted only of CC and MLO stereo views of a single breast. The software was modified to check for the presence of images for only a single breast and, for such a case, to determine which breast was imaged and which was missing. The image panels in the Overview stereo image for the missing breast were left blank, and the corresponding keypad keys to display single views at full resolution were disabled.

The fourth modification, a highly significant one, was required to solve a problem resulting from the fact that there is independent control of each x-ray exposure on the GE Senographe digital mammography unit used to acquire the stereo mammograms in our study. The GE unit determines the exposure parameters for each x-ray acquisition from a brief pre-exposure through the central portion of the breast. The two images of a stereo pair are acquired while the breast remains compressed and fixed in place. The point-of-view of the breast is changed by a 10-degree rotation of the x-ray tube between the two exposures. Most of the time, this small change in point-of-view results in only very minor changes in the exposure parameters determined by the GE unit. However, occasionally, the two exposures differ significantly, in spite of the small

change in the point-of-view of the breast. The result is that the grayscale histograms for the two images, while typically identical in shape, are shifted apart. The effect of this in the stereo display is that the two images of the stereo pair have different brightness, making stereo fusion of the pair difficult or impossible. We were able to solve the problem, as follows. Following an exposure, the GE unit effectively computes the grayscale histogram of the image and stores a measure closely related to the grayscale mean for the breast tissue in the DICOM header. We decided on a new, desired grayscale mean that we wanted all images to share, and used the difference between each stored mean and the desired mean to correct the pixel grayscale values of each image. Thus, after correction, each case image had the same, constant grayscale mean. This solution not only equated the brightness of stereo image pairs suffering this problem, but also had the helpful side effect of equating the brightness of all stereo views for a case since all images are being corrected to exactly the same grayscale mean. In particular, this improves the appearance of the Overview image in which all 4 views (CC and MLO views of each breast) are displayed together in a single stereo image at half spatial resolution.

#### **4. Study data forms**

We made extensive modifications to the standard and stereo reading forms (Forms A1 and A2, respectively) and the consensus meeting resolution form (Form B). Almost all of these changes were implemented prior to the start of case accrual. We have also developed additional forms to describe work-up examination results (Form C), and biopsy results (Form D). We describe the changed or new forms below. Copies of the set of forms currently in use are included as Appendices A-E.

##### **4.1 Standard and Stereo Reading forms (Forms A1 and A2)**

These forms were extensively modified from those included in the Year 2 Annual Report to both improve and increase the information collected in each reading. We now ask whether prior mammographic films were present during the reading, and for an assessment of the glandular tissue composition of the imaged breasts. We also modified the finding-localization diagrams to resemble the presentation seen in the mammographic images.

For each identified finding requiring work-up, we added: (1) a rating of the finding's conspicuity, on a 10-point scale, (2) the BI-RADS category assigned to the finding, and (3) the recommended work-up actions for the finding.

We also added a section to the form permitting the mammographer to identify the type and location of benign findings seen in the images. Finally, we added an item for the BI-RADS category assignment *for the case*, considering all identified findings, and also a space for comments.

#### 4.2 Consensus meeting resolution form (Form B)

If one or more findings are reported either in the standard reading or in the stereo reading, or in both, then the two mammographers who conducted those readings meet to compare the standard and stereo images and resolve any difference in those findings, reporting the results of their meeting on Form B. The first section of the form is used to establish the correspondence between findings detected in each reading, or to establish that a particular finding detected in one reading modality was *not detected* in the other reading modality. For each finding, the basis for any discrepancy is determined. The location of each finding is indicated on a breast diagram, and joint recommendations are made for work-up examinations.

#### 4.3 Work-up results form (Form C)

For each finding identified in the consensus meeting as requiring work-up, this form captures the results of all work-up examinations that were performed. Each examination result is indicated by a lesion-type code or a no-finding code. Finally, the mammographer conducting the work-up examinations assigns, for each finding, a final summary work-up code and BI-RADS category, estimates the likelihood of malignancy, and indicates whether biopsy is required.

#### 4.4 Biopsy results form (Form D)

This form captures the pathology analysis results of each finding that has been biopsied. Pathology of a finding is indicated by one or more codes indicating different types of benign and malignant disease. In addition, the form records the type of biopsy performed (percutaneous or excision) and whether the biopsied lesion was benign or malignant.

### 5. Transfer of case images from Emory to BBN

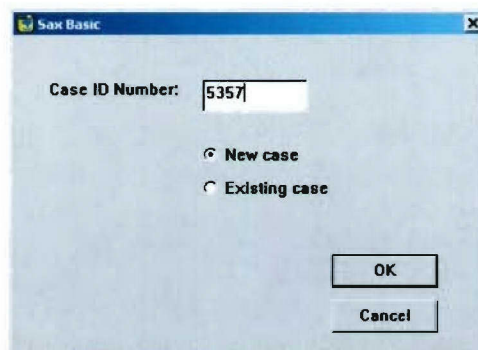
We wrote a software application that allows a user to specify one or more patient cases to be anonymized and transferred to BBN via FTP transfer. For each image of a specified case, the identifying DICOM header tags for patient name, date of birth, and hospital ID number are all deleted and replaced with the patient's assigned sequential project study number. All of the anonymized images for the case are then compressed into a ZIP file and transmitted by FTP transfer to BBN. There the case images are retrieved and stored on the stereo display workstation at BBN, and are reviewed there for stereo quality control.

### 6. Project database

Case data are entered into a database designed and maintained within the SPSS statistical analysis package. A total of 284 variables have been defined within the database, derived from the patient's clinical history form, and the study data forms A-D. For a typical case, only a relatively small fraction of these variables are used. In order to streamline the data entry process, SPSS scripts have been written that present the person entering the data with a series of

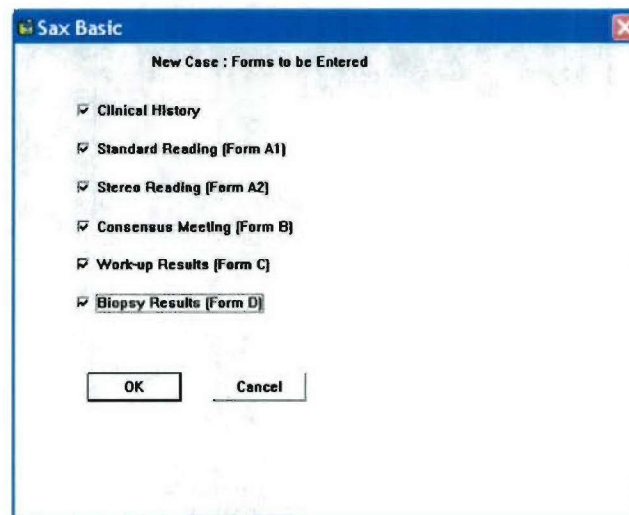
electronic forms that are facsimiles of the hardcopy study forms. These are shown below with an illustrative, imaginary case.

After entering the study case number and indicating whether this is a new or existing case (Figure 3), the user is presented with a form permitting selection of the study forms to be entered (Figure 4). For new cases, the Clinical History form, and the Standard and Stereo Reading forms are pre-selected by default. By way of illustration, we show filled out data entry forms for an imaginary new patient, study number 5357.

A screenshot of a Windows-style dialog box titled "Sax Basic". It contains a label "Case ID Number:" followed by a text input field containing the number "5357". Below the input field are two radio buttons: "New case" (which is selected) and "Existing case". At the bottom right of the dialog are two buttons: "OK" and "Cancel".

**Figure 3. Study case ID number screen.**

In our example, this patient has findings detected both in the standard and stereo readings, which lead to further work-up examinations, and, ultimately on to biopsy. Consequently, all study data forms are shown as checked off on the "Forms to be Entered" screen, shown below in Figure 4.

A screenshot of a Windows-style dialog box titled "Sax Basic" with a subtitle "New Case : Forms to be Entered". It contains a list of six items, each with a checked checkbox: "Clinical History", "Standard Reading (Form A1)", "Stereo Reading (Form A2)", "Consensus Meeting (Form B)", "Work-up Results (Form C)", and "Biopsy Results (Form D)". At the bottom of the dialog are two buttons: "OK" and "Cancel".

**Figure 4. Forms to be entered screen.**

For a new case such as this, the first data entry screen presented is the Clinical History screen, shown below in Figure 5. Here we see that this patient is 74 years old, has had both breasts imaged in this study, has several close female relatives who have had breast cancer, has previously had breast cancer herself in the Right breast, for which she received a lumpectomy, radiation therapy, and chemotherapy.

SDM CLINICAL HISTORY FORM: CASE 5357

Age: 74 Breasts imaged: ☒ Both breasts ☐ Right only ☐ Left only Race: ☒ White ☐ Black/African American ☐ Hispanic ☐ American Indian, Eskimo, Aleut ☐ Asian, Pacific Islander ☐ Other

BRCA status: ☒ Unknown ☐ Negative ☐ Positive

Reason for exam: ☒ Routine screening ☐ Additional exam from recent study ☐ Short interval follow-up ☐ Breast implants ☐ Review of outside study ☐ Planned breast reduction ☐ Planned radiation therapy ☐ Work-up exam ☐ Problems

Problems: ☐ R ☐ L New lump ☐ R ☐ L Bloody discharge ☐ R ☐ L Non-bloody ☐ R ☐ L Difficult physical exam ☐ R ☐ L Implant problem ☐ R ☐ L Skin thickening or retraction ☐ R ☐ L Other lump or thickening ☐ R ☐ L Nipple problem ☐ R ☐ L Pain in the breast ☐ R ☐ L Cancer elsewhere ☐ R ☐ L Large nodes under arm

Risk factors: ☐ No family history ☒ Aunt ☐ Grandmother ☐ Cousin ☒ Mother ☒ Sister ☐ Unknown family history ☒ Patient breast cancer ☐ Patient endometrial cancer ☐ Patient ovarian cancer ☐ Biopsied high-risk lesion ☒ Patient past menopause ☐ Patient no children ☐ First child after age 30

Hormone treatment: No ☐ Past ☒ Current ☐ Birth control pill ☒ Depovera ☐ Norplant ☐ Estrogen ☐ Progesterone ☒ Tamoxifen

Previous procedures? ☐ No ☒ Yes ☐ R ☒ L Cyst Aspiration ☒ R ☐ L Needle biopsy ☒ R ☐ L Excisional biopsy ☒ R ☐ L Lumpectomy ☐ R ☐ L Mastectomy ☒ R ☐ L Radiation therapy ☐ R ☐ L Breast reduction ☐ R ☐ L Implant removal

Menstrual history: 12 Age when periods started 24 Age at 1st full-term pregnancy 52 Age at natural menopause Age at Hysterectomy Age at left ovary removal Age at right ovary removal 3 Number of live births

Implants? ☒ None ☐ Left ☐ Right ☐ Both

Prior chemotherapy? ☐ No ☒ Yes

OK Cancel

Figure 5. Clinical history entry screen.

The next data entry screen presented is the Standard Reading form (A1), shown below in Figure 6. It captures the dates of imaging and reading, the reader's initials, whether prior films were present at the reading, a general measure of breast density, and the number of findings, if any, in each breast. In this case, a mass is reported in the left breast and architectural distortion in the right breast. For each lesion, we record its location, the reader's confidence that the lesion really exists, the conspicuity of the lesion, the reader's estimate of the probability of malignancy, the BI-RADS category assigned to the lesion, and the recommended work-up examinations to be performed.

The reader is also asked to check off all benign findings seen in either breast, assign a BI-RADS category for the case, considering all findings: 0 (requires work-up), 1 (normal case), or 2 (clear or known benign findings). Space is left for any comments the reader may wish to leave.

**PATIENT STUDY NUMBER: 5357**

**DATE OF EXAM:** 7/15/05

**DATE OF READING:** 7/15/05

**READER'S INITIALS:** cd

1. Prior films present? ☒ Yes ☐ No

2. Breast composition: ☐ Fatty ☐ Scattered densities ☒ Heterogen. dense ☐ Extremely dense

3. Number findings in each breast: LEFT: 1 RIGHT: 1

FINDING	Code	Side	Loc.	Conf. Real	Conspic.	Prob Malign	Bi-rads	Spot	Mag	Roll	90	Exag	US	Other
1.	m	l	uo	75	6	15	0	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
2.	a	r	il	20	3	10	0	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3.								<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4.								<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

**BENIGN FINDINGS**

Mass		Benign c's		Unchanged c's		Rad therapy		IM nodes		Needle biopsy		Excision		Unchanged asym		Other:	
R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Case BI-RADS: 0

Comments:

OK Cancel

Figure 6. Standard reading data entry screen.

The next data entry screen, shown in Figure 7 below, corresponds to the Stereo Reading form (A2) and captures exactly the same set of information as in the standard reading. The stereo reading is completely independent of the standard reading, and is carried out by a different reader. Over time, each reader will read equal numbers of cases in the standard reading condition and the stereo reading condition.

In our illustrative case, the stereo reader has detected a single finding, a mass in the Left breast, but no finding in the Right breast.

**Sax Basic** SDM DATA FORM A2 - STEREO READING

PATIENT STUDY NUMBER: 5357

DATE OF EXAM: 7/15/05

DATE OF READING: 7/16/05

READER'S INITIALS: mn

1. Prior films present? ☒ Yes ☐ No

2. Breast composition: ☐ Fatty ☐ Scattered densities ☒ Heterogen. dense ☐ Extremely dense

3. Number findings in each breast: LEFT: 1 RIGHT: 0

FINDING	Code	Side	Loc.	Conf.	Real	Conspic.	Prob Malign	Birads	Spot	Mag	Roll	90	Exag	US	Other
1.	m	L	uo	90	9	25	0		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
2.									<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3.									<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4.									<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

**BENIGN FINDINGS**

	Mass		Benign c's		Unchanged c's		Rad therapy		IM nodes		Needle biopsy		Excision		Unchanged asym		Other:	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
UO	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
UI	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LI	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LO	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Case BIRADS: 0

Comments:

OK Cancel

Figure 7. Stereo reading data entry screen.

If either the standard or stereo reading, or both, result in detection of one or more findings, then the two readers meet to review and compare the standard and stereo images in order to understand and resolve the differences, if any, in their respective findings. The results are captured on the Consensus Resolution of Findings form (B) and entered on the Consensus data entry screen, shown below in Figure 8.

First, the two readers agree on the correspondence between findings seen in the standard reading and findings seen in the stereo reading, arriving at a total number of distinct findings. In our illustration, the mass seen in the Left breast by the standard reader is the same mass seen and reported by the stereo reader, as indicated by Finding 1 in Figure 8. However, the architectural distortion reported by the standard reader in the Right breast (Finding 2) was not reported by the stereo reader (indicated by the Stereo Code 0). The two readers make new recommendations about work-up exams to be performed on each finding.

**Sax Basic**

**SDM DATA FORM B - CONSENSUS RESOLUTION OF FINDINGS**

PATIENT STUDY NUMBER: 5357

DATE OF CONSENSUS MEETING: 7/16/05

Total Number of findings (both breasts): 2

FINDING	Std. Code	Stereo Code	Side	Loc.	Basis	Spot	Mag	Roll	90	Exag	US	Other
1.	m	m	l	uu	0	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	
2.	a	0	r	ll	i	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
3.						<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	
4.						<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

Case BIRADS: 0

Comments: Architectural distortion seen in standard images appears to be superimposed tissue in the stereo images.

OK Cancel

**Figure 8. Consensus resolution of findings data entry screen.**

The results of the work-up examinations are recorded on the Work-up Results study form (C), and captured by the Work-up data entry screen, shown in Figure 9 below. For each distinct finding identified in the consensus meeting, the outcome of each work-up exam performed is recorded by the type of lesion identified, or by “0” if no lesion is detected.

In our illustrative case, the mass in the Left breast is confirmed in several different types of work-up exam (including a solid mass detected by ultrasound). This lesion is categorized as BI-RADS 5, signifying that it is probably malignant and must be biopsied. On the other hand, the architectural distortion reported in the standard reading in the Right breast, is not found on any of several work-up examinations. In the standard reading, the case was assigned as BI-RADS 0 (requiring work-up) and, thus, it was a *false positive* detection.

Sax Basic

SDM DATA FORM C - WORK-UP RESULTS

PATIENT STUDY NUMBER: 5357

DATE OF WORK-UP: 7/20/05

DATE OF READING: 7/20/05

READER'S INITIALS: kg

Total Number findings: 2

FINDING	Standard	Stereo	Spot	Mag	Roll	90	Exag	US	Other-Type	Other-Result	Final Code	Prob Malign	Biopsy?	BI-RADS
1.	m	m	m	m				sm			m	60	<input checked="" type="checkbox"/>	5
2.	a	0	0	0							0	0	<input type="checkbox"/>	1
3.													<input type="checkbox"/>	
4.													<input type="checkbox"/>	

Case BI-RADS: 5

Comments

OK

Cancel

Figure 9. Work-up results data entry screen.

The final Biopsy data entry screen, shown below in Figure 10, is used to enter data from the Biopsy Results form (D). For each biopsied lesion, the nature of the biopsy (percutaneous or excision), the classification as Benign or Malignant, and the assignment of one or more pathology codes from a list are recorded.

In this case, a core needle biopsy of the mass was performed and it was found to be malignant. The lesion was coded as invasive ductal carcinoma and ductal carcinoma in situ.

**Sax Basic** SDM DATA FORM D - BIOPSY RESULTS

PATIENT STUDY NUMBER: 5357

DATE OF BIOPSY: 1/22/05

PATHOLOGIST'S INITIALS: dk

Total Number Findings: 1

FINDING	Work-up Code	Biopsy Type	Malign/Benign	Path Code 1	Path Code 2	Path Code 3	Path Code 4	Path Code 5
1.	m	<input checked="" type="radio"/> Percutan <input type="radio"/> Excision	<input type="radio"/> Benign <input checked="" type="radio"/> Malignant	idc	ds			
2.		<input checked="" type="radio"/> Percutan <input type="radio"/> Excision	<input type="radio"/> Benign <input type="radio"/> Malignant					
3.		<input checked="" type="radio"/> Percutan <input type="radio"/> Excision	<input type="radio"/> Benign <input type="radio"/> Malignant					
4.		<input checked="" type="radio"/> Percutan <input type="radio"/> Excision	<input type="radio"/> Benign <input type="radio"/> Malignant					

Comments:

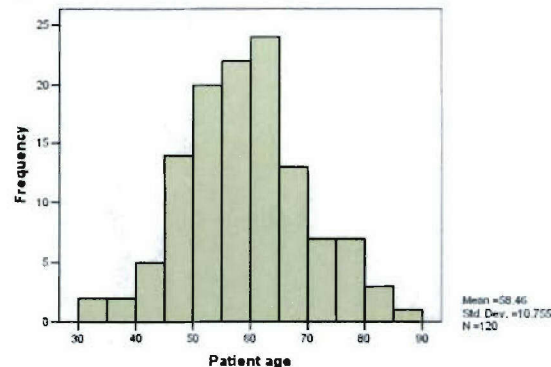
OK Cancel

**Figure 10. Biopsy results data entry screen.**

## 7. Patient sample demographics

We began enrolling patients into this study in January, 2005. As of the end of Year 3 of the project (31 July 2005), we had processed 120 patients, each at elevated risk for the development of breast cancer.

The mean age of the enrolled patients is 58.5 years, with a distribution as shown below in Figure 11. In this sample, 61% (73 of 120) of the patients are post-menopausal, while the remaining 39% (47 of 120) are pre-menopausal.



**Figure 11. Distribution of patient age.**

The distribution of patients by ethnic origin is as follows:

White	89.2% (107 of 120)
Black/African American	08.3% (10 of 120)
Hispanic	01.7% (2 of 120)
Other	00.8% (1 of 120)

Worthy of note, 80% (96 of 120) of the patients have had prior breast cancer, and of those, 52% (50 of 96) have had a complete or partial mastectomy of one breast. Interestingly, the mastectomy was of the right breast for 62% of the patients (31 of 50) and of the left breast in only 38% of the patients (19 of 50). This difference almost attains statistical significance ( $p=.09$ , 2-tailed  $t$ -test).

## 8. Study results

With only 120 patients entered into the study database at the end of Year 3, there is not yet enough data to support any statistical analyses of the results.

We note, however, the observation that over the first 75 patients entered into the study, there were 5 cases in which suspicious architectural distortion was detected as a finding in the standard, non-stereo reading, and reported as BI-RADS 0 (requiring work-up). For these same cases, there were no corresponding detections in the stereo reading, and the stereo report was either BI-RADS 1 (a normal case) or BI-RADS 2 (clear or known benign disease), with no

requirement for further work-up. The following work-up exam, required by the results of the standard reading, revealed that there was no lesion present in any of these cases. Thus, the standard reading resulted in a *false positive* detection in each of these cases—one that was avoided in the stereo reading that correctly read the patient images as normal or benign. Had the stereo mammogram been the standard of clinical care for screening, these patients would not have been called back for a further, needless work-up examination.

### **KEY RESEARCH ACCOMPLISHMENTS (Year 3)**

- Developed a new stereo display workstation based on a pair of high-resolution Planar LCD flat panel displays (“StereoMirror”). Assembled two copies of the stereo workstation, one at BBN and the other at the Breast Imaging Clinic at Emory University.
- Modified and enhanced the software program, SDM Viewer, used by the radiologists for reading stereo mammograms on the stereo display workstation.
- Completed and refined the set of study data forms to be used for collecting data for each enrolled subject.
- Developed the study database and a set of data entry screens to facilitate entry of patient data into the database.
- Began the enrollment of patients into the study, including both standard and stereo imaging of each enrolled elevated-risk patient.

## **REPORTABLE OUTCOMES (Year 3)**

### **PRESENTATIONS**

Green, P., Getty, D.J. (2004). Stereoscopic digital mammography. In September, 2004, Dr. Getty traveled to Bethesda with Pat Green, Director of Technology at Planar, to make a presentation regarding stereoscopic digital mammography, the Planar StereoMirror display, and the Emory clinical trial of stereo mammography to research and regulatory staff of the FDA. The purpose of the presentation was to acquaint the FDA with the stereo mammography technology, the scope of the clinical trial, and to begin preliminary discussions with them regarding steps needed to obtain future FDA approval for stereo mammography.

Getty D.J. (2004) Stereoscopic digital mammography. Invited presentation at the First Americas Display Engineering and Applications Conference (ADEAC '04), Ft. Worth, Oct. 25-27, 2004.

Getty, D. J. (2004). Stereoscopic and biplane imaging. Special Refresher Course presentation at the meetings of the Radiological Society of North America, Chicago, November 28 - December 3, 2004.

### **PUBLICATIONS**

Getty DJ. (2004) Stereoscopic digital mammography. Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC '04), Ft. Worth, 2004, 11-14.

## CONCLUSIONS

During the early months of Year 3 of the project, we engaged in a number of activities in preparation for the start of patient enrollment at the beginning of 2005. The new stereo display workstation was installed at both BBN and in the Breast Imaging Clinic at Emory University. This hardware for the new stereo display was based on the advanced Planar StereoMirror technology, developed during Year 2 of the project. This stereo display incorporates two Planar high-resolution, monochrome LCD flat-panel displays, and a special half-silvered mirror. The research staff at BBN and the mammographers at Emory are all very pleased with the high quality and superb resolution of the stereo images on the new display.

A second major activity was the completion of the software application, SDM Viewer, for controlling the new stereo display. We have added functionality to the program and further improved the human factors of the interface for the mammographers. A third activity was the completion and refinement of the set of study data forms to be filled out for each enrolled case by the Emory staff. With the completion of the data forms, we then designed and constructed an SPSS database for the accumulating data, programmed data entry screens to facilitate the data entry process, and began writing data analysis routines to carry out descriptive and statistical analyses of the data.

We began enrolling patients into the study in January, 2005. The rate of enrollment was more than adequate during the first few months as a result of extensive publicity about the start of the clinical trial in the greater Atlanta area. More recently, the rate of patient inquiry has fallen off, raising concerns about our ability to generate a sufficiently large case sample by the end of the project. There were 120 patients enrolled at the end of Year 3 (July 31, 2005). We have taken several steps to expand our communication of information about the clinical trial to the eligible community—women at elevated risk for development of breast cancer. These steps include: (1) on-hold messages about the trial during calls to Emory Health Care, (2) more local media coverage, and (3) involvement of the Southeastern Regional Office of the American Cancer Society. We are hopeful that these measures will allow us to increase the enrollment rate to 15 to 20 patients per week, permitting us to accumulate more than 1000 cases, sufficient to conduct reliable statistical analyses of the study results, particularly of the accuracy of patient recall.

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## **APPENDICES**

- Appendix A1: SDM study form A1: Standard Reading
- Appendix A2: SDM study form A2: Stereo Reading
- Appendix B: SDM study form B: Consensus Meeting Resolution
- Appendix C: SDM study form C: Work-up Results
- Appendix D: SDM study form D: Biopsy Results
- Appendix E: Getty DJ. (2004) Stereoscopic digital mammography. Proceedings of the First Americas Display Engineering and Applications Conference (ADEAC '04), Ft. Worth, 2004, 11-14.

**SDM DATA FORM A1 - STANDARD READING**

PATIENT STUDY NUMBER: \_\_\_\_\_

DATE OF EXAM: \_\_\_\_\_

DATE OF READING: \_\_\_\_\_

READER'S INITIALS: \_\_\_\_\_

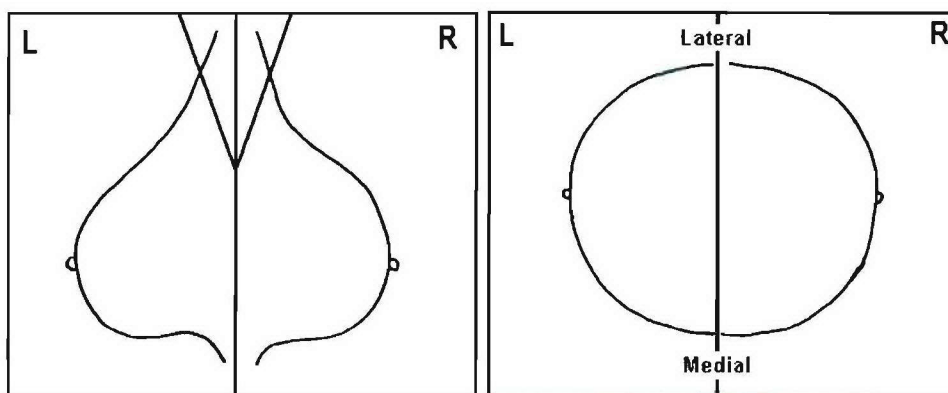
1. Prior films present with interpretation? ☐ Yes ☐ No2. Breast composition: ☐ Fatty ☐ Scattered densities ☐ Heterogeneously dense ☐ Extremely dense3. Number of findings in each breast that require work-up: LEFT \_\_\_\_\_ RIGHT \_\_\_\_\_  
(If NONE, skip to 6)

4. On the picture below mark all of those findings.

Use the following codes: M-Mass, M/C – Mass w/ calcifications, F- Focal asymmetry,

A- Architectural distortion, C – Clustered Calcifications.

(Numbers starting with 1 can be appended to the code for more than one finding of the same type).



5. For each finding, rate the following characteristics and indicate recommended work-up action(s):

Finding Code	Confidence of True Finding (0 to 100 scale)	Conspicuity (1=Barely visible to 10=Highly visible)	Likelihood of Malignancy (0 to 100 scale)	BIRADS Category for finding	Indicate recommended work-up action(s)						
					Spot	Mag	Roll	90	Exag.	US	Other (Specify)

6. Indicate all benign findings (Select all that apply):

Circumscribed mass(es)	Benign calcifications	Unchanged low suspicion calcifications	Post radiation therapy/ lumpectomy	IM nodes
<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>
Unchanged post percutan. needle biopsy <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Post benign surgical excision <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Unchanged focal/ general asymmetry <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Other: <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	

7. BIRADS Category for patient: \_\_\_\_\_

Comments:

**SDM DATA FORM A2 - STEREO READING**

PATIENT STUDY NUMBER: \_\_\_\_\_

DATE OF EXAM: \_\_\_\_\_

DATE OF READING: \_\_\_\_\_

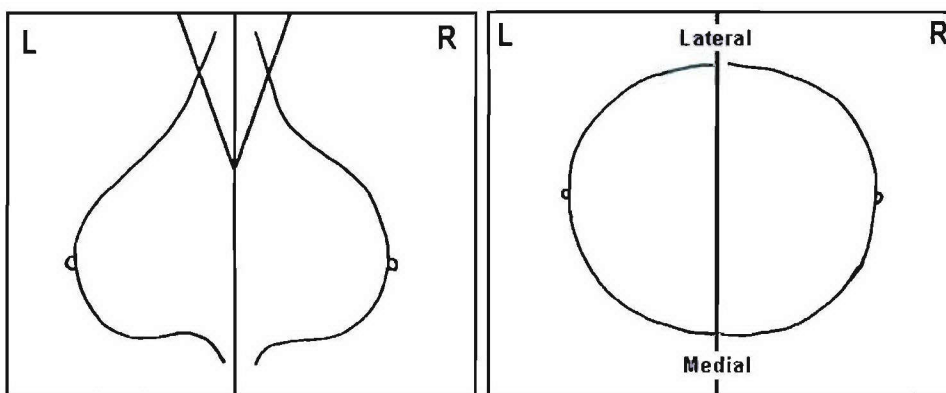
READER'S INITIALS: \_\_\_\_\_

1. Prior films present with interpretation? ☐ Yes ☐ No2. Breast composition: ☐ Fatty ☐ Scattered densities ☐ Heterogeneously dense ☐ Extremely dense3. Number of findings in each breast that require work-up: LEFT \_\_\_\_\_ RIGHT \_\_\_\_\_  
(If NONE, skip to 6)

4. On the picture below mark all of those findings.

Use the following codes: **M**-Mass, **M/C** – Mass w/ calcifications, **F**- Focal asymmetry,**A**- Architectural distortion, **C** – Clustered Calcifications.

(Numbers starting with 1 can be appended to the code for more than one finding of the same type).



5. For each finding, rate the following characteristics and indicate recommended work-up action(s):

Finding Code	Confidence of True Finding (0 to 100 scale)	Conspicuity (1=Barely visible to 10=Highly visible)	Likelihood of Malignancy (0 to 100 scale)	BIRADS Category for finding	Indicate recommended work-up action(s)						
					Spot	Mag	Roll	90	Exag.	US	Other (Specify)

6. Indicate all benign findings (Select all that apply):

Circumscribed mass(es)	Benign calcifications	Unchanged low suspicion calcifications	Post radiation therapy/lumpectomy	IM nodes
<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	<u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>
Unchanged post percutan. needle biopsy <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Post benign surgical excision <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Unchanged focal/general asymmetry <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	Other: <u>Right      Left</u> <input type="checkbox"/> UOQ <input type="checkbox"/> <input type="checkbox"/> UIQ <input type="checkbox"/> <input type="checkbox"/> LIQ <input type="checkbox"/> <input type="checkbox"/> LOQ <input type="checkbox"/>	

7. BIRADS Category for patient: \_\_\_\_\_

Comments:

**SDM DATA FORM B – CONSENSUS /RESOLUTION OF FINDINGS**

PATIENT STUDY NUMBER: \_\_\_\_\_

DATE OF EXAM: \_\_\_\_\_

DATE OF CONSENSUS MEETING: \_\_\_\_\_

READER INITIALS:      STANDARD      STEREO      \_\_\_\_\_

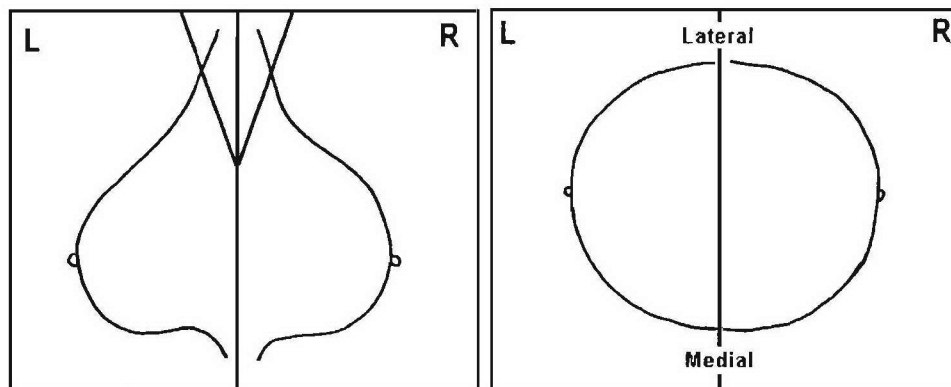
1. For each finding (from either the standard or stereo readings), indicate the correspondence between the findings in the standard and stereo readings.

Use the following codes: **M**-Mass, **M/C** – Mass w/ calcifications, **F** – Focal asymmetry, **A** – Architectural distortion, **C** – Clustered Calcifications, **ND** – Not detected in that reading.

*(Numbers starting with 1 can be appended to the code for more than one finding of the same type).*

Finding #	Finding Code		Basis of Discrepancy (if any)
	Standard	Stereo	
1			
2			
3			
4			

2. On the picture below mark each of the findings, using the above sequential finding numbers (1,2,3,4).



3. Recommended work-up actions:

Finding #	Indicate work-up action(s)						
	Spot	Mag	Roll	90	Exaggerated	Ultra-sound	Other (specify)
1							
2							
3							
4							

4. BIRADS Category for patient: \_\_\_\_\_ Comments: \_\_\_\_\_

**SDM DATA FORM C – WORK-UP RESULTS**

PATIENT STUDY NUMBER: \_\_\_\_\_

DATE OF WORK-UP EXAM: \_\_\_\_\_

DATE OF READING: \_\_\_\_\_

READER'S INITIALS: \_\_\_\_\_

Use the following codes: **M** – Mass, **M/C** – Mass w/ calcifications, **F** – Focal asymmetry, **A** – Architectural distortion, **C** – Calcifications, **Ø** – No finding.  
*(Numbers starting with 1 can be appended to the code for more than one finding of the same type).*

For Ultrasound, use the following codes: **SM** – Solid mass, **FM** – Fluid-filled mass

## 1. Work-up performed:

Finding #	Finding Code		Indicate work-up finding results (using above codes)						
	Std.	Stereo	Spot	Mag	Roll	90	Exag-gerated	Ultra-sound	Other (specify)
1									
2									
3									
4									

## 2. For each finding, determine a final, combined finding code, rate the likelihood of malignancy, specify whether biopsy is required, and the BIRADS category:

Finding #	Final Work-up Finding Code	Likelihood of Malignancy (0 to 100 scale)	Biopsy Required? (Y or N)	BIRADS Category for finding
1				
2				
3				
4				

## 3. BIRADS Category for patient: \_\_\_\_\_

Comments:

**SDM DATA FORM D – BIOPSY**

PATIENT STUDY NUMBER: \_\_\_\_\_

DATE OF BIOPSY: \_\_\_\_\_

PATHOLOGIST'S INITIALS: \_\_\_\_\_

Use the following codes: **M** – Mass, **M/C** – Mass w/ calcifications, **F** – Focal asymmetry,  
**A** – Architectural distortion, **C** – Calcifications.

*(Numbers starting with 1 can be appended to the code for more than one finding of the same type).*

Biopsy results:

Finding #	Final Work-up Finding Code	Type of Biopsy: Excision (E), Percutaneous (P)	Malignant (M) or Benign (B)?	Pathology Code(s) <i>(Use pathology codes listed below)</i>
1				
2				
3				
4				

**PATHOLOGY CODES****Benign**

- |  |     |
|--|-----|
| 1. Atypical Columnar Hyperplasia         | ACH |
| 2. Atypical Ductal Hyperplasia           | ADH |
| 3. Atypical Lobular Hyperplasia          | ALH |
| 4. Benign Cystosarcoma Phylloides        | BPT |
| 5. Columnar Hyperplasia                  | CH  |
| 6. Cysts                                 | BC  |
| 7. Diabetic mastopathy                   | DF  |
| 8. Ductal Ectasia                        | DE  |
| 9. Ductal Hyperplasia (usual type)       | DH  |
| 10. Fat necrosis                         | FN  |
| 11. Fibroadenoma                         | FA  |
| 12. Fibrocystic Disease                  | FCD |
| 13. Granular Cell Tumor                  | GC  |
| 14. Hamartoma                            | HB  |
| 15. Lipoma                               | LB  |
| 16. Lobular Hyperplasia                  | LH  |
| 17. Papilloma                            | PA  |
| 18. Pseudoagiomatous stromal hyperplasia | PSH |
| 19. Radial Sclerosing Scar               | RS  |
| 20. Sclerosing Adenosis                  | SA  |
| 21. Other Benign                         | OB  |

**Malignant**

- |                                 |     |
|---------------------------------|-----|
| 1. Ductal Carcinoma In Situ     | DS  |
| 2. Invasive Ductal Carcinoma    | IDC |
| 3. Invasive Lobular Carcinoma   | ILC |
| 4. Invasive Papillary Carcinoma | IP  |
| 5. Lymphoma                     | LA  |
| 6. Medullary Carcinoma          | MC  |
| 7. Mucinous Carcinoma           | CC  |
| 8. Tubular Carcinoma            | TC  |
| 9. Other Malignant              | OM  |

## 2.3: Invited Paper: Stereoscopic Digital Mammography

**David J. Getty**

BBN Technologies

10 Moulton St., Cambridge, MA, USA 02138

getty@bbn.com

**Abstract:** *Stereo mammography holds the promise of improving the early detection of breast cancer by providing the radiologist with a volumetric view of the breast. In a preliminary study, stereo mammography was shown to significantly improve diagnostic accuracy, and also revealed a number of lesions that were not detected in corresponding 2D film views. A clinical trial now underway at Emory University, will compare stereo digital mammography to non-stereo digital mammography in a screening context, for improved sensitivity and accuracy of lesion detection and for reduced rate of patient recall.*

**Keywords:** Stereoscopic imaging; stereoscopic display, digital mammography; breast cancer; lesion detection.

### Introduction

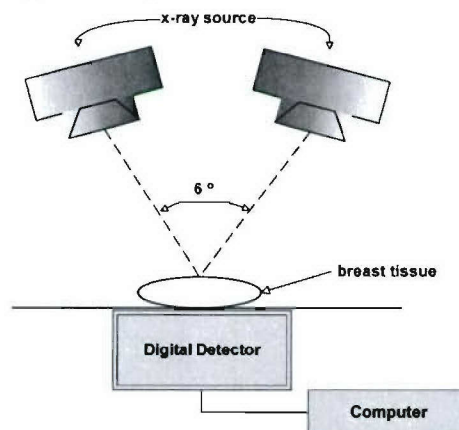
Mammography, in its standard form requiring the reading of two orthogonal 2D views, is widely regarded as one of the most difficult radiographic exams to interpret. Subtle lesions may be masked by superimposition of overlying or underlying normal breast tissue, and thus be undetectable. The need to confirm a possible lesion seen in one view on the second, orthogonal view is also very problematic. Even when a lesion is confirmed on both views, understanding its three-dimensional shape and characteristics from these views can be difficult, particularly for clusters of micro-calcifications (small dots of calcium, on the order of 100-200  $\mu\text{m}$  in diameter) where finding a one-to-one correspondence of elements is usually not possible.

Stereoscopic digital mammography holds the promise of significantly reducing these problems. In a stereo mammogram, the radiologist is provided with a stereoscopic x-ray view of the breast, in which a subtle lesion is directly seen volumetrically, separated from overlying and underlying normal tissue in depth. A true lesion can be confirmed in a single stereo view, at a particular locus and orientation within the breast. Moreover, the volumetric shape of a mass or architectural distortion, and the geometric structure of clustered calcifications, can be directly appreciated, without the need for mental reconstruction from the two separate 2D views.

### Acquisition of a Stereo Mammogram

A stereo mammogram consists of two x-ray images of the breast taken sequentially from slightly different points of view. As illustrated in Figure 1, the x-ray source is rotated by 6 to 10 degrees between exposures while the position of the x-ray detector and the breast remain fixed in position. The digital detector captures each x-ray image directly and

stores it as a data file on a computer. In the research reported here, stereo mammograms were acquired on a GE Senographe® 2000D full-field-of-view digital mammography unit that had been modified to permit off-axis images to be acquired.



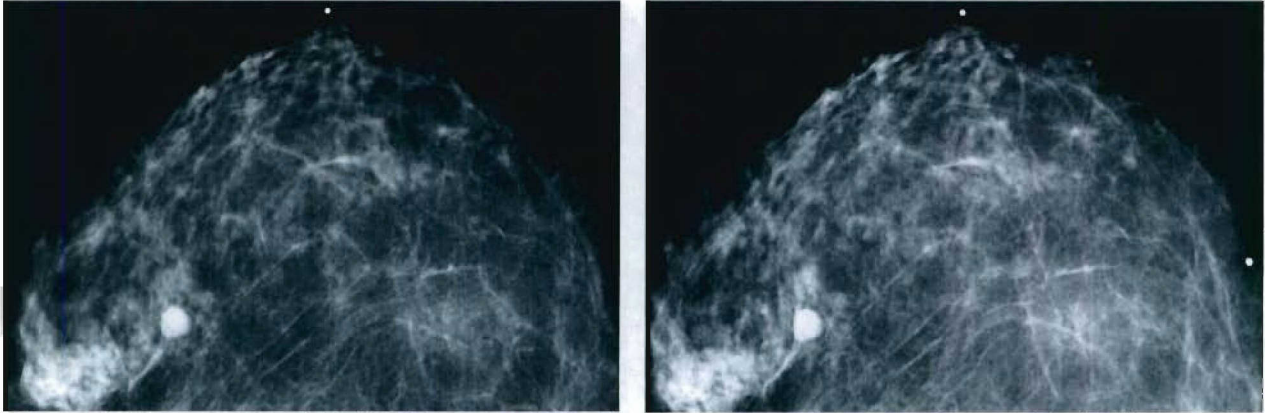
**Figure 1.** Acquisition of a stereoscopic digital mammogram.

An example of a stereo pair of digital mammograms containing a benign mass is shown in Figure 2. Although the two views look very similar, there are subtle differences in the two images resulting from their having been captured from slightly different points-of-view. When one image is presented in isolation to each eye, the visual system is able to fuse the two images into a single image seen in depth. (It is possible to experience this here crudely by crossing your eyes and concentrating on the middle image of three that you will see).

### Display of a Stereo Mammogram

Several different methodologies are available for display of stereo mammograms. Regardless of the methodology employed, the requirement is that each of the two images that comprise the stereo pair be uniquely channeled to one, and only one, eye.

**Temporally-Multiplexed Stereo Displays.** One class of stereo display systems utilizes time-multiplexed display of the stereo pair. The two images are presented alternately in rapid succession—typically at a 120 Hz frame rate—on a single display monitor. The user wears special stereo-viewing glasses whose lenses are LCD shutters. The stereo-viewing glasses are synchronized to the display and alternately block each eye's view of the display as the two images are displayed alternately—effectively routing each

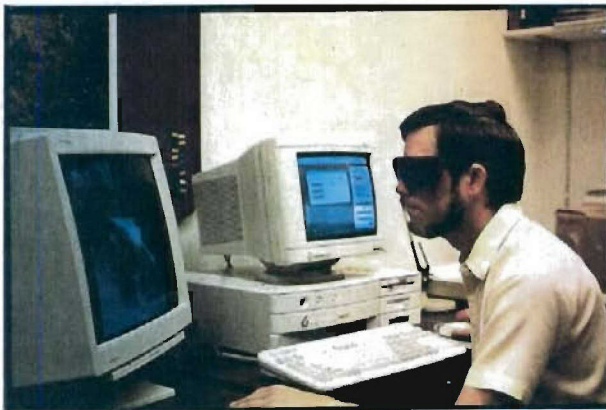


**Figure 2.** Stereoscopic pair of digital mammograms, with a benign mass located at about 8 o'clock. It is possible to see the images in depth by crossing your eyes and attending to the central image.

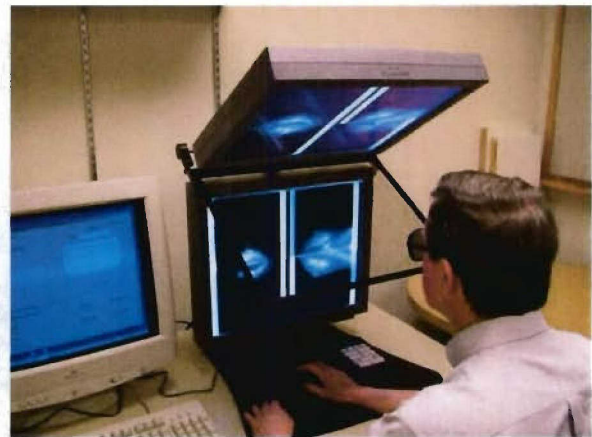
image to only one eye. The user's visual system fuses the two images into a single image seen in depth. We used this method of stereo display in our earlier research. Stereo mammograms were presented on a high-resolution (2K x 2K), monochrome MegaScan CRT monitor, and viewed using StereoGraphics CrystalEyes® stereo glasses, shown in Figure 3.

*Spatially-multiplexed Stereo Displays.* Another class of stereo display systems conveys the two images to the two eyes simultaneously through spatially separate channels. There are a number of different technologies for accomplishing this. One example is the Planar SD5000 stereo display which is based on the Ferguson Stereo Mirror concept [1]. In this system, shown in Figure 4, two high-resolution (2.5K x 2K), monochrome LCD flat panel monitors (C5i) are mounted one above the other, with a 120-degree angle separating the two surfaces. The image emitted from the upper monitor is polarized in one direction while the image emitted from the lower monitor is polarized in the orthogonal direction. A "half-silvered" glass plate is mounted between the two monitors, bisecting the angle between them. The user wears lightweight

passive polarized glasses, with the Left and Right lenses polarized orthogonally, such that the user's Right eye sees only the image on the lower monitor, transmitted through the glass plate, and the user's Left eye sees only the image on the upper monitor, reflected from the coated glass. The perceptual result is a single fused image, seen in depth. This display system will be used in a clinical trial of stereo digital mammography just now underway at Emory University. The advantages of this system over our earlier CRT-based system are (1) a much brighter display (luminance of the LCD monitor is 500 cd/m<sup>2</sup>; luminance of the CRT monitor was 150 cd/m<sup>2</sup>), and (2) lightweight passive polarized glasses instead of the heavier, shuttering polarized LCD glasses. The one disadvantage of this spatially-multiplexed system is a greater sensitivity to loss of the stereo depth effect with head tilt. With the passive glasses, as the user's head is tilted away from vertical, the polarization axes of the two lenses rotate away from horizontal and vertical, allowing leakage into each eye of the image intended only for the other eye. This problem does not arise with the temporally-multiplexed systems.



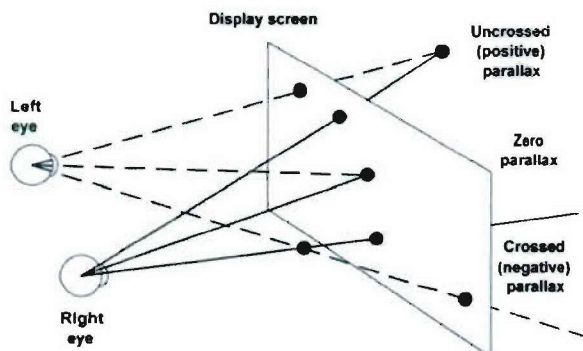
**Figure 3.** Temporally-multiplexed stereo display.



**Figure 4.** Spatially-multiplexed stereo display.

### Control of the Displayed Stereo Image

**Horizontal Parallax.** Because the two images of a stereo pair are acquired from slightly different points of view, the location of a particular object in the two images will be separated horizontally, by an amount that depends directly on the location of the object in depth. There are three types of parallax, illustrated in Figure 5. If a point belonging to an object is displayed at exactly the same position in the left- and right-eye images, then it is said to have “zero parallax.” The perceptual effect is that the object is seen to lie at the surface of the display screen.



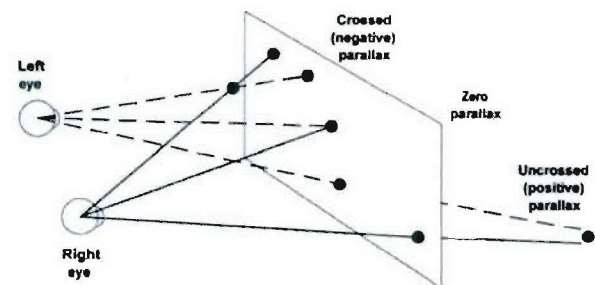
**Figure 5.** Illustration of uncrossed, zero, and crossed parallax of pairs of corresponding points shown on a single display screen.

In the other two cases, a point belonging to an object is displayed at different locations in the left- and right-eye image. If the right-eye point is displaced to the right of the left-eye point, then the object will be perceived to lie behind the screen surface. The larger the separation, the farther the object will be from the screen surface. This case is called “uncrossed” or “positive” parallax. In the third case, if the right-eye point is displaced to the left of the left-eye point, then the object will be perceived to lie in front of the display surface. Again, the larger the separation, the farther the object will be from the screen surface, towards the observer.

**Inversion of Displayed Depth.** While the stereo point-of-view of the imaged object is predetermined by the point-of-view at the time of image acquisition, there are two other aspects of the viewed volume that the user can manipulate [2]. First, one can invert depth by swapping the two images—presenting the left-eye image to the right eye and the right-eye image to the left eye. Consider the two points corresponding to uncrossed parallax in Figure 5. When we swap the images, as shown in Figure 6, the dot previously seen by the left-eye is now seen by the right-eye, and vice versa. So now we have crossed parallax and the object will be seen not behind the screen, but in front of it. Similarly, dots originally displaying crossed parallax will now have uncrossed parallax. Thus, objects originally seen in front of the screen will now be seen behind it, and vice versa.

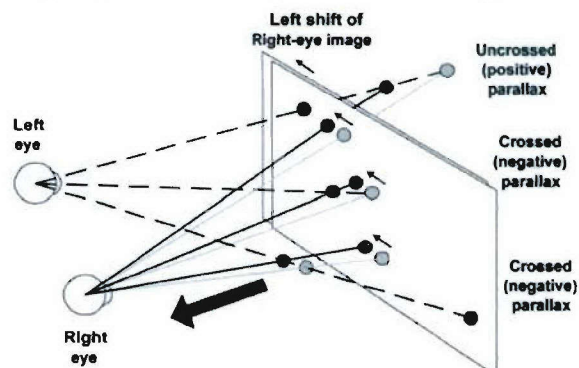
Dots with zero parallax will still have zero parallax, and remain seen at the screen surface. Thus, the effect of swapping images is to invert depth—much like reaching into a glove and pulling it inside out. If, in addition to swapping the two images, one also spins each image 180 degrees about a vertical axis, then the inverted depth image is seen as if one had walked around the object to view it from the backside.

Inverting depth can be important in stereo viewing, especially of stereo mammograms. It is easier to attend to objects seen in the foreground compared to those seen in the background, especially when there is a clutter of objects in the foreground. By allowing a radiologist to invert depth, tissue originally at the back of the displayed volume can be moved to the front of the volume, making it easier to perceive and inspect.



**Figure 6.** Inversion of perceived depth, achieved by swapping the two images between eyes.

**Shifting Location of the Displayed Volume.** A second aspect of the viewed volume that can be manipulated is the location of the displayed volume in depth with respect to the screen surface. If one shifts the right-eye image slightly to the left while holding the left-eye image fixed, as shown in Figure 7, then the horizontal parallax of all points will be changed in the direction of uncrossed parallax. Points originally with uncrossed parallax will have larger



**Figure 7.** Shifting location of the displayed volume uncrossed parallax, and points with crossed parallax will have decreased crossed parallax. The perceived effect is to shift the entire viewed volume forward in depth, towards

the observer, with the amount of shift in depth proportional to the amount of left lateral shift of the right-eye image. Shifting the right-eye image in the other direction, to the right, will shift the viewed volume away from the viewer relative to the screen surface. It is only the amount of relative shift of the two images that matters, so one could just as well make shifts to the left-eye image, or to both. In fact, splitting a desired amount of shift between the two images will minimize the amount of stereo image lost at the left and right edges of the display.

Control of location of the viewed volume is useful in that many people initially find it difficult to perceive a displayed volume that begins at the screen surface and comes towards one in space. Usually, they are more comfortable with a displayed volume that starts at the screen surface and goes back into the monitor. It's always possible to achieve this condition by using relative shifts of the two images. On the other hand, with increasing experience, people often come to prefer a displayed volume that comes out into space.

**Stereo Cursor.** A stereo cursor is useful for allowing a user to point out a region of interest in the stereo image, in depth, to another user. If one draws a cursor icon in both images of the stereo pair at the same location then there is no horizontal parallax and the cursor is seen to lie at the surface of the display screen. If the icon is drawn with horizontal separation in the two images, then the cursor is perceived to lie either in front of the screen (for crossed parallax) or behind the screen (for uncrossed parallax), with depth proportional to the amount of separation.

### Results of a Preliminary Study of Stereoscopic Digital Mammography

A preliminary study has recently been completed to evaluate the contribution of stereo mammography in the diagnosis of breast cancer [3]. We acquired both standard film and stereo digital mammographic images on a number of women scheduled for biopsy of a suspicious focal breast lesion. The stereo mammograms were acquired on a pre-clinical version of the GE Senographe® 2000D digital mammography unit, with a 6-degree shift in the x-ray tube between exposures. We conducted a reading study to determine the diagnostic accuracy achieved by standard film alone compared to standard film read together with the stereo mammogram. A second goal, added as the project progressed, was to obtain preliminary data on the capability of stereo mammography to detect subtle lesions that were not visible in the corresponding film studies.

The reading study was conducted with 5 experienced mammographers individually reading 129 path-proven cases containing 137 malignant and benign lesions (several cases had more than one lesion). The reading of each case was conducted in two successive stages. The reader first examined the full set of film mammograms from the diagnostic study that led to biopsy, rating the probability that the lesion was malignant on a scale of 0 to 100. The

reader was then shown the stereo view of the lesion and asked to again rate the probability of malignancy. The stereo image was always a CC view acquired just prior to biopsy. For each case, the reader was also asked to report on any additional lesions seen in either the films or the stereo mammogram, in addition to the known, biopsied lesion.

We conducted an ROC-based analysis of the accuracy of the readers' ratings of the likelihood of malignancy for the two viewing conditions. Diagnostic accuracy, measured by Az (the area under the ROC curve), was 0.83 when the readers viewed the film study alone, rising to 0.86 when readers also viewed the stereo mammogram. This is a statistically significant improvement.

Perhaps a more important finding was that readers detected a very significant number of likely new lesions in the stereo mammogram—ones that were not detected in the films. In all, 39 new lesions were reported in the 129 cases, corresponding to 30% of the cases. Of these 39 lesions, 30 were reported as masses, 6 as new calcification clusters, and 3 as architectural distortions. While we do not have independent truth for many of these newly detected lesions, we do have truth for one subset: masses detected only in the stereo mammogram in association with prior film-detected calcifications. Of 12 such cases, the pathologic report for 11 of the 12 cases reported that the calcifications were located within a mass (most often a fibroadenoma).

### A Clinical Trial of Stereoscopic Digital Mammography

We are now beginning a large clinical study of stereoscopic digital mammography at the Emory Breast Clinic, funded by the Army's Breast Cancer Research Program. In this study, about 2000 women at elevated risk for development of breast cancer will receive both standard (non-stereo) digital screening mammograms and a stereo digital mammogram. We will compare independent readings of each case, conducted by different mammographers, in stereo and standard, non-stereo reading conditions. We hypothesize that stereo imaging will lead to earlier detection of small, subtle lesions and will, by increasing the reader's confidence, result in a reduced rate of recall of patients for further work up.

### References

1. J. L. Fergason, U.S. Patent number 6703988 B1.
2. Getty, D.J. "Stereoscopic and Biplane Imaging," *Advances in Digital Radiography: RSNA Categorical Course in Diagnostic Radiology Physics 2003*. RSNA Press, 2003, pp. 199-209.
3. Getty, D.J., Pickett, R.M., D'Orsi, C.J. "Stereoscopic digital mammography: improving detection and diagnosis of breast cancer." In: *Computer Assisted Radiology and Surgery (CARS-2001)*. Berlin, Germany: Elsevier Science B.V., 2001, pp. 431-435.